

# Appendix A

## Technology Assessment

Economic evaluation of alternative digester technologies applied to prospective digester projects for the dairies of King County. Includes three technologies applied through a wide range of project sizes, from a single farm to the total dairy cow census of the county.

### List of Exhibits

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Throughout the digester feasibility report and throughout this appendix, various tables and charts are presented which originate from the copyrighted software product “**Economic Feasibility of Biogas Recovery and Utilization**”. The software was developed by EnRRG specifically to evaluate prospective anaerobic digester projects such as those in King County, and has evolved through years of use in various potential projects.

The computer model uses a combination of technical and economic equations to mimic the thought process for evaluating economic phenomena. Capital costs are simulated by modeling the individual components, sizing them according to the relevant technical equations and pricing them through application of economic values. Income and operating costs are based upon materials volumes calculated within the technical model, and unit costs/prices which may be unique to a specific project.

The model relies on various databases as a source of “standard” technical and economic factors from which to perform the calculations. Standard values can be used unchanged or they can be modified by the researcher as more appropriate data are assembled for a particular project. In this manner, a “primitive” evaluation for a project can be performed very quickly using standard, database derived, values for all but the most basic of descriptive factors. As, and if, the project evolves, the starting point values can be replaced by actual data which more accurately describe the project, or project scenario, being evaluated.

#### Exhibit A-1 – Differentiating Factors for Technology Assessment

		Plug	Mixed	
		Flow	Mesophilic	Thermophilic
Retention	days	30	30	15
Temperature	deg F	95	95	135
VS Conversion	Ft3/# VS	5	5.5	6
Residuals Value	per ton	\$10	\$10	\$20

Three technologies were evaluated and compared as part of this study. The comparison was accomplished by changing a minimum of factors which describe the critical differences between the three cases. Of the four factors varied, three are technical factors and one is an economic factor. Those factors and their values used in the evaluation are shown in Exhibit A-1 above. Another differentiating consideration between the cases, which is done automatically by the model, is that the digester vessel for the plug flow technology is constructed in-ground from concrete while the containment vessels for the two mixed digester technologies are constructed from above-ground glass-fused-to-steel tanks.

## **Exhibit A-2 – Waste Characteristics Database**



														Process Water
		Raw Waste			Lbs/day/1000# Unit Weight									GPD/Unit
Unit		Per Day/1000#												Gal
Desc.	Weight	Lbs	Fit	TS	VS	COD	BOD5	N	P	K	TDS	C:N ratio		
<b>--Components--</b>														
<b>----Dairy</b>														
Lactating Cow	Hd	1400	80.0	1.30	12.00	10.00	8.90	1.60	0.45	0.07	0.26	0.85	10	
Dry Cow	Hd	1400	82.0	1.30	12.00	10.00	8.90	1.60	0.45	0.07	0.26		13	
Heifer	Hd	900	85.0	1.30	9.14	7.77	8.3	1.3	0.31	0.04	0.24		14	
<b>----Beef</b>														
Hi Forage Feedlot	Hd	1000	59.1	0.95	6.78	6.04	6.11	1.36	0.31	0.11	0.24		11	
Hi Energy Feedlot	Hd	1000	51.2	0.82	5.91	5.44	5.61	1.36	0.3	0.094	0.21		10	
Calf	Hd	500	58.2	0.93	7.54	6.41	6	1.3	0.3	0.1	0.2		12	
Cow	Hd	900	63.0	1.00	7.3	6.2	6	1.2	0.33	0.12	0.26		10	
<b>----Swine</b>														
Grow/Finish Pig	Hd	135	63.4	1.00	6.34	5.4	6.06	2.08	0.42	0.16	0.22	1.29	7	1.1
Gilt	Hd	200	32.8	0.53	3.28	2.92	3.12	1.08	0.24	0.08	0.13		7	1.5
Gestation Sow	Hd	400	27.2	0.44	2.5	2.13	2.37	0.83	0.19	0.063	0.123		6	1.1
Lact Sow & Litter	Hd	500	60.0	0.96	6	5.4	5.73	2	0.47	0.15	0.3		6	4
Boar	Hd	500	20.5	0.33	1.9	1.7	1.37	0.65	0.15	0.05	0.1		6	1.4
Nursery Pig	Hd	30	106.0	1.70	10.6	8.8	9.8	3.4	0.6	0.25	0.35		8	0.27
<b>----Poultry</b>														
Layer-AE	000 Hd	4000	60.5	0.93	15.1	10.8	13.7	3.7	0.83	0.31	0.34		7	50
Layer-High Rise	000 Hd	4000	24.0	0.60	12	8.6			0.425	0.275	0.3		9	40
Broiler&Litter	000 Hd	2500	35.0	0.60	26.5	21.4			0.68	0.34	0.4	2.89	9	
Turkey&Litter	000 Hd	12500	24.3	0.40	16.1	13			0.88	0.4	0.45		7	
Duck	000 Hd	4000			12	7	9.5	2.5	0.7	0.3	0.05		6	
<b>----Litter&amp;Misc</b>														
Wood Shavings	Ton/Day	2000												
Straw	Ton/Day	2000												
Newspaper	Ton/Day	2000												
<b>----Municipal</b>														
Food Wastes	Ton/Day	2000	1000	18	250	200								
Raw Sludge	Ton/Day	2000	1000	16	40	30			3.2	0.36				
Digested Sludge	Ton/Day	2000	1000	16	40	21			1.5	0.67	0.1			
<b>----Food Processing</b>														
Dairy-Sweet Whey	000# Mill	1000	2060	33	142	131	26.8	154						
<b>--Enterprises--</b>														
Farrow-to-Finish	Sows	1450.5	55.81	0.89	5.53	4.71	5.25	1.81	0.37	0.14	0.20			9.891
Farrow-to-Half Fin	Sows	984.75	52.23	0.83	5.14	4.39	4.87	1.69	0.35	0.13	0.20			6.096
Farrow-to-Feeder	Sows	519	42.20	0.68	4.07	3.48	3.81	1.34	0.28	0.10	0.18			2.301
Farrow-to-Wean	Sows	450	32.42	0.52	3.07	2.67	2.89	1.02	0.24	0.08	0.15			1.68
Finishing	Head	135	63.40	1.00	6.34	5.40	6.06	2.08	0.42	0.16	0.22			1.1
Dairy	Milkers	1580	80.84	1.30	11.67	9.75	8.83	1.57	0.43	0.07	0.26			
Feedlot	Head	1000	51.20	0.82	5.91	5.44	5.61	1.36	0.30	0.09	0.21			
Layer Flock	000 Hd	4000	60.50	0.93	15.10	10.80	13.70	3.70	0.83	0.31	0.34			50
Broiler Flock	000 Hd	2500	35.00	0.60	26.50	21.40			0.68	0.34	0.40			
Turkey Growout	000 Hd	12500	24.30	0.40	16.10	13.00			0.88	0.40	0.45			

The table above illustrates the database for characterizing waste materials which can be inputs for an anaerobic digester. For this project, the values for "lactating cow" and "dry cow" were used, as well as that for wood shavings. After an item is selected from the standard database it can be further modified to more accurately reflect the conditions found with the particular project under study.

### Exhibit A-3 -- Examples of Basic Technical Calculations

Calculation of Energy Production from Volatile Solids				
	<b>Lbs of Volatile Solids</b>	<b>6,750</b>	Lbs	
X	<b>BioGas Production/Lb VS</b>	<b>6.00</b>	Ft3/Lb	
=				
	<b>BioGas Production</b>	<b>40,500</b>	Ft3	
X	<b>Percent Methane</b>	<b>60%</b>		
=				
	<b>Methane Equivalency</b>	<b>24,300</b>	Ft3	
X	<b>Btu Content of Methane</b>	<b>1,000</b>	Btu/Ft3	
=				
	<b>Btu Production</b>	<b>24,300,000</b>	Btus	
	<b>Btu per Kwh of Electricity</b>	<b>3450</b>	Btu/Kwh	
/	<b>Efficiency of Generator</b>	<b>35%</b>		
=				
	<b>Btu Input per Kwh Produced</b>	<b>9,857</b>	Btus	
	<b>Btu Production</b>	<b>24,300,000</b>	Btus	
/	<b>Btu Input per Kwh Produced</b>	<b>9,857</b>	Btu/Kwh	
=				
	<b>Kwh of Electricity</b>	<b>2,465</b>	Kwh	
/	<b>Hours/day</b>	<b>24</b>	Hours/day	
=				
	<b>Average Production Rate</b>	<b>103</b>	KW	
X	<b>Capacity Factor</b>	<b>125%</b>		
=				
	<b>Genset Size</b>	<b>128</b>	KW	

The two tables above illustrate the calculative process involved in transforming animal numbers into daily volatile solids, digester vessel sizing, daily biogas production, daily electricity production and generator sizing. Numbers in blue text are technical factors, which are very critical components of the digestion process for converting waste (volatile solids) to energy. In all of the reports produced from the model, any number that is printed in blue is one that can be varied to suit the project scenario being evaluated.

# Exhibit A-4 – Plug Flow Digester Calculations

<b>Digester Parameters Related to Size</b> <b>Plug Flow -- Mesophilic</b>					
<u>No of Cows</u>	<u>Volatile Solids Lbs/day</u>	<u>Digester Capacity 000 Gal</u>	<u>Daily BioGas 000 ft3</u>	<u>Ave Power KW</u>	
300	4,050	256	20	49	
500	6,750	426	34	81	
1000	13,500	853	68	163	
2500	33,750	2,132	169	407	
6000	81,000	5,116	405	976	
9000	121,500	7,673	608	1,464	

<u>No of Cows</u>	<u>Gas Energy MMBtu</u>	<u>Elect Production MWh</u>	<u>Digester Heating % Total Btu</u>	<u>Recovered Residuals Tons</u>	<u>CO2e Tons</u>
300	12	427	18%	1,330	1,587
500	20	712	15%	2,217	2,646
1000	41	1,425	13%	4,433	5,292
2500	101	3,562	14%	11,083	13,229
6000	243	8,548	13%	26,599	31,750
9000	365	12,822	13%	39,899	47,625

<u>No of Cows</u>	<u>Investment \$000</u>	<u>Investment \$/Cow</u>	<u>Net Revenue \$000</u>	<u>Net Revenue \$/Cow</u>	<u>ROI</u>
300	\$433	\$1,443	\$11	\$37.08	-6%
500	\$621	\$1,243	\$35	\$70.41	1%
1000	\$1,090	\$1,090	\$95	\$95.41	6%
2500	\$2,917	\$1,167	\$276	\$110.41	7%
6000	\$6,432	\$1,072	\$697	\$116.24	9%
9000	\$10,079	\$1,120	\$1,059	\$117.63	8%

Retention	30 days
Temperature	95 deg F
VS Conversion	5 Ft3/# VS
Residuals Value	\$10 per ton

# Exhibit A-5 – Mixed Mesophilic Digester Calculations

Digester Parameters Related to Size					
Mixed Digester -- Mesophilic					
No of Cows	Volatile Solids Lbs/day	Digester Capacity 000 Gal	Daily BioGas 000 ft3	Ave Power KW	
300	4,050	256	22	54	
500	6,750	426	37	89	
1000	13,500	853	74	179	
2500	33,750	2,132	186	447	
6000	81,000	5,116	446	1,073	
9000	121,500	7,673	668	1,610	
No of Cows	Gas Energy MMBtu	Elect Production MWh	Digester Heating % Total Btu	Recovered Residuals Tons	CO2e Tons
300	13	470	16%	1,330	1,746
500	22	784	14%	2,217	2,910
1000	45	1,567	12%	4,433	5,821
2500	111	3,918	12%	11,083	14,552
6000	267	9,403	12%	26,599	34,925
9000	401	14,104	12%	39,899	52,387
No of Cows	Investment \$000	Investment \$/Cow	Net Revenue \$000	Net Revenue \$/Cow	ROI
300	\$536	\$1,785	\$15	\$49.59	-5%
500	\$766	\$1,533	\$41	\$82.93	1%
1000	\$1,333	\$1,333	\$108	\$107.93	5%
2500	\$3,726	\$1,491	\$307	\$122.93	5%
6000	\$8,024	\$1,337	\$773	\$128.76	7%
9000	\$12,525	\$1,392	\$1,171	\$130.15	7%
Retention		30 days			
Temperature		95 deg F			
VS Conversion		5.5 Ft3/# VS			
Residuals Value		\$10 per ton			

# Exhibit A-6 – Mixed Thermophilic Digester Calculations

Digester Parameters Related to Size					
Mixed Digester -- Thermophilic					
No of Cows	Volatile Solids Lbs/day	Digester Capacity 000 Gal	Daily BioGas 000 ft3	Ave Power KW	
300	4,050	128	24	59	
500	6,750	213	41	98	
1000	13,500	426	81	195	
2500	33,750	1,066	203	488	
6000	81,000	2,558	486	1,171	
9000	121,500	3,837	729	1,756	
No of Cows	Gas Energy MMBtu	Elect Production MWh	Digester Heating % Total Btu	Recovered Residuals Tons	CO2e Tons
300	15	513	30%	1,330	1,905
500	24	855	26%	2,217	3,175
1000	49	1,710	22%	4,433	6,350
2500	122	4,274	22%	11,083	15,875
6000	292	10,258	21%	26,599	38,100
9000	437	15,387	21%	39,899	57,150
No of Cows	Investment \$000	Investment \$/Cow	Net Revenue \$000	Net Revenue \$/Cow	ROI
300	\$483	\$1,609	\$32	\$106.44	3%
500	\$697	\$1,394	\$70	\$139.78	8%
1000	\$1,234	\$1,234	\$165	\$164.78	12%
2500	\$3,151	\$1,260	\$449	\$179.78	13%
6000	\$6,816	\$1,136	\$1,114	\$185.61	15%
9000	\$10,351	\$1,150	\$1,683	\$187.00	15%
Retention Temperature		15 days			
VS Conversion		135 deg F			
Residuals Value		6 Ft3/# VS			
		\$20 per ton			

# Exhibit A-7 – Summary of Digester Attributes by Technology and Size

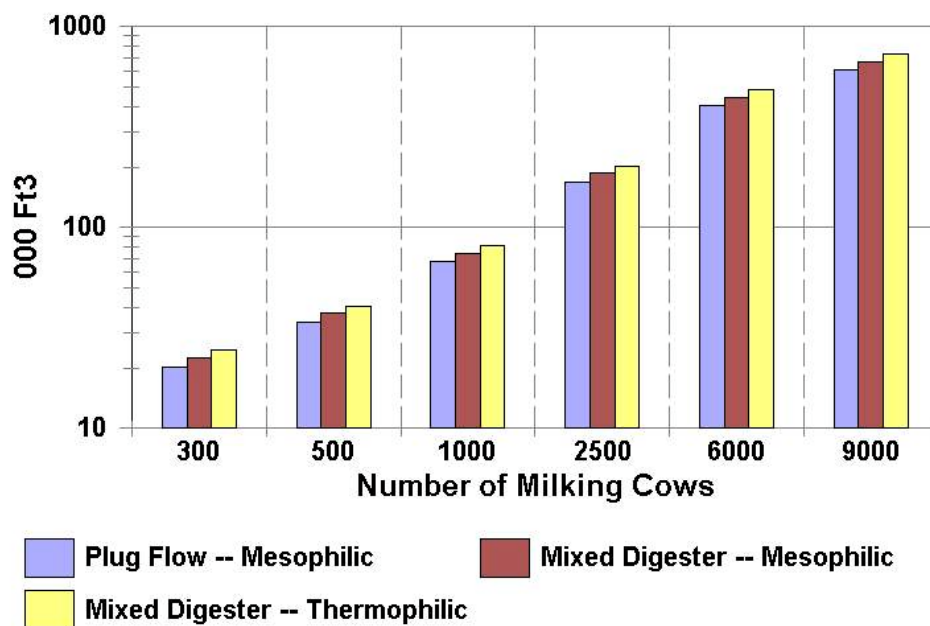
Digester Parameters Related to Size					Digester Parameters Related to Size					
Plug Flow -- Mesophilic					Plug Flow -- Mesophilic					
No of Cows	Volatile Solids Lbs/day	Digester Capacity 000 Gal	Daily BioGas 000 ft3	Ave Power KW	No of Cows	Gas Energy MMBtu	Elect Production MWh	Digester Heating Total Btu	Recovered Residuals Tons	CO2e Tons
300	4,050	256	20	49	300	12	427	18%	1,330	1,587
500	6,750	426	34	81	500	20	712	15%	2,217	2,646
1000	13,500	853	68	163	1000	41	1,425	13%	4,433	5,292
2500	33,750	2,132	169	407	2500	101	3,562	14%	11,083	13,229
6000	81,000	5,116	405	976	6000	243	8,548	13%	26,599	31,750
9000	121,500	7,673	608	1,464	9000	365	12,822	13%	39,899	47,625
Mixed Digester -- Mesophilic					Mixed Digester -- Mesophilic					
300	4,050	256	22	54	300	13	470	16%	1,330	1,746
500	6,750	426	37	89	500	22	784	14%	2,217	2,910
1000	13,500	853	74	179	1000	45	1,567	12%	4,433	5,821
2500	33,750	2,132	186	447	2500	111	3,918	12%	11,083	14,552
6000	81,000	5,116	446	1,073	6000	267	9,403	12%	26,599	34,925
9000	121,500	7,673	668	1,610	9000	401	14,104	12%	39,899	52,387
Mixed Digester -- Thermophilic					Mixed Digester -- Thermophilic					
300	4,050	128	24	59	300	15	513	30%	1,330	1,905
500	6,750	213	41	98	500	24	855	26%	2,217	3,175
1000	13,500	426	81	195	1000	49	1,710	22%	4,433	6,350
2500	33,750	1,066	203	488	2500	122	4,274	22%	11,083	15,875
6000	81,000	2,558	486	1,171	6000	292	10,258	21%	26,599	38,100
9000	121,500	3,837	729	1,756	9000	437	15,387	21%	39,899	57,150

Digester Parameters Related to Size					
Plug Flow -- Mesophilic					
No of Cows	Investment \$000	Investment \$/Cow	Revenue \$000	Revenue \$/Cow	ROI
300	\$433	\$1,443	\$11	\$37.08	-6%
500	\$621	\$1,243	\$35	\$70.41	1%
1000	\$1,090	\$1,090	\$95	\$95.41	6%
2500	\$2,917	\$1,167	\$276	\$110.41	7%
6000	\$6,432	\$1,072	\$697	\$116.24	9%
9000	\$10,079	\$1,120	\$1,059	\$117.63	8%
Mixed Digester -- Mesophilic					
300	\$536	\$1,785	\$15	\$49.59	-5%
500	\$766	\$1,533	\$41	\$82.93	1%
1000	\$1,333	\$1,333	\$108	\$107.93	5%
2500	\$3,726	\$1,491	\$307	\$122.93	5%
6000	\$8,024	\$1,337	\$773	\$128.76	7%
9000	\$12,525	\$1,392	\$1,171	\$130.15	7%
Mixed Digester -- Thermophilic					
300	\$483	\$1,609	\$32	\$106.44	3%
500	\$697	\$1,394	\$70	\$139.78	8%
1000	\$1,234	\$1,234	\$165	\$164.78	12%
2500	\$3,151	\$1,260	\$449	\$179.78	13%
6000	\$6,816	\$1,136	\$1,114	\$185.61	15%
9000	\$10,351	\$1,150	\$1,683	\$187.00	15%

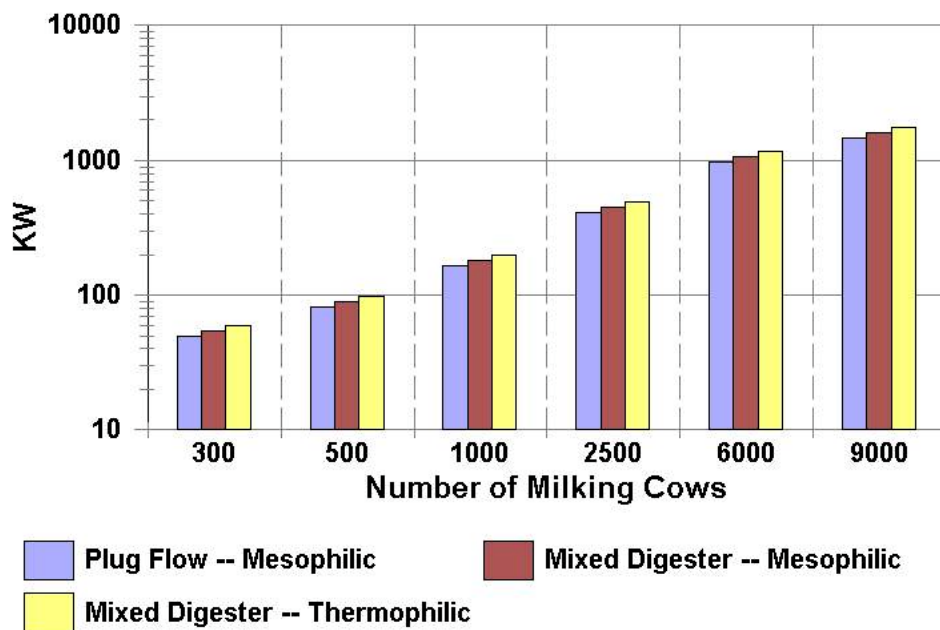
## Digester Technology Comparison

Daily Biogas Production



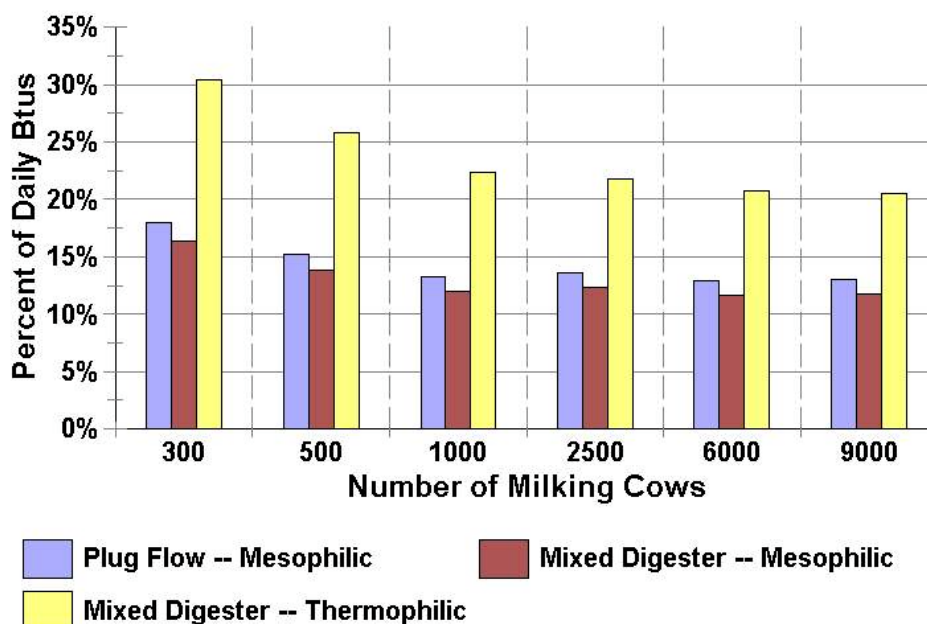
## Digester Technology Comparison

Ave. Power Production



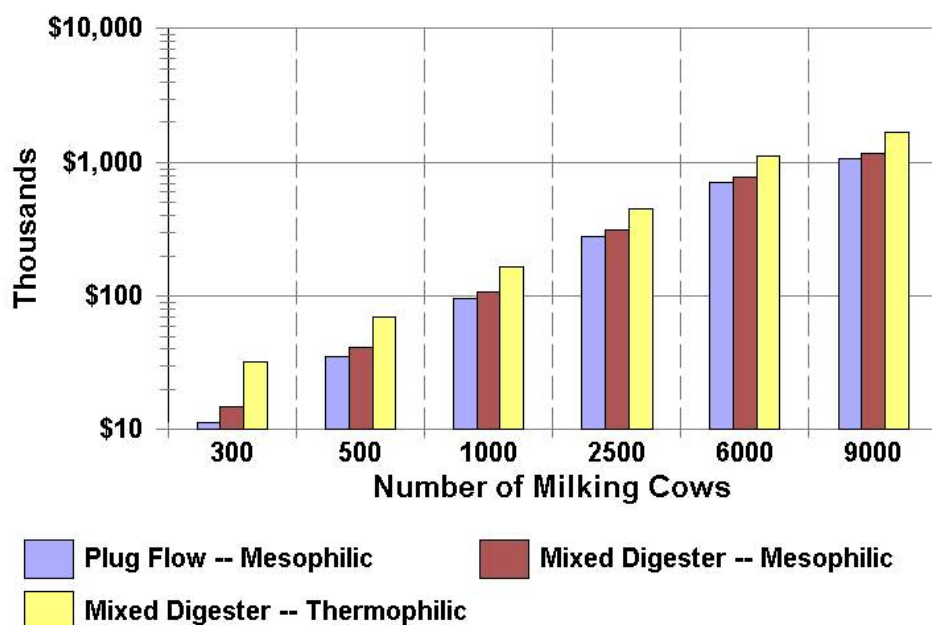
## Digester Technology Comparison

Energy Used For Digester Heat



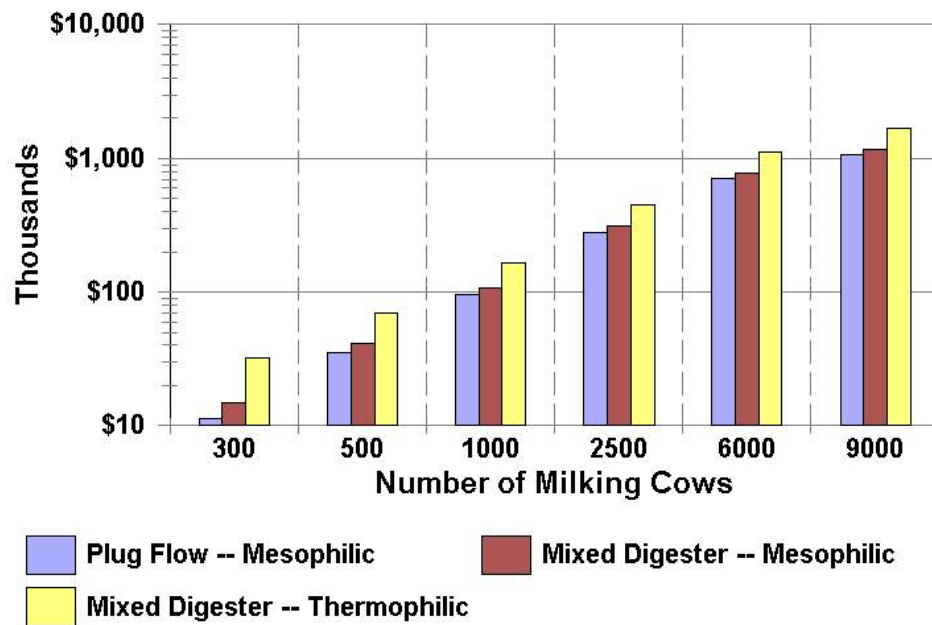
## Digester Technology Comparison

Annual Net Revenue



## Digester Technology Comparison

Annual Net Revenue



## Digester Technology Comparison

Estimated Investment per Cow

